Army Research Laboratory

High-Temperature Testing Fixture for Ceramic O-Rings

by David Gray and Robert Kaste

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14. ABSTRACT
A test method is being used to determine the tensile strength of ceramic O-ring specimens as a part of an effort at the U.S. Army Research Laboratory to develop ceramic materials for gun barrel applications. The tensile strength of the inner surface of a ceramic O-ring specimen is determined by applying a compressive load at 2 points diametrically opposite each other on the specimen. Testing was conducted at room temperature and at 700 ºC. A test fixture was developed to facilitate the placement and alignment of the O-ring specimen during the 700 ºC testing. The fixture is described in this report, and preliminary data on silicon nitride (Si3N4) is provided to show the utility of the fixture.

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1. Introduction

Ceramic tubes are under investigation at the U.S. Army Research Laboratory (ARL) as potential liners for gun barrel applications. It is important to accurately determine the strength of the materials in order to predict the performance of a tube. One method to determine the strength is to diametrally compress O-ring specimens that have been sectioned from tubes of the candidate materials. Previous work has shown that this test methodology is the best way to determine the strength of a large ceramic tube when fracture initiates on the inner surface of the tube.[1, 2]

The O-ring specimen is positioned into the testing machine between two platens, one of which is a gimbaled mount to compensate for any misalignment. A typical gimbaled platen such as a universal joint is shown in figures 1 and 2.

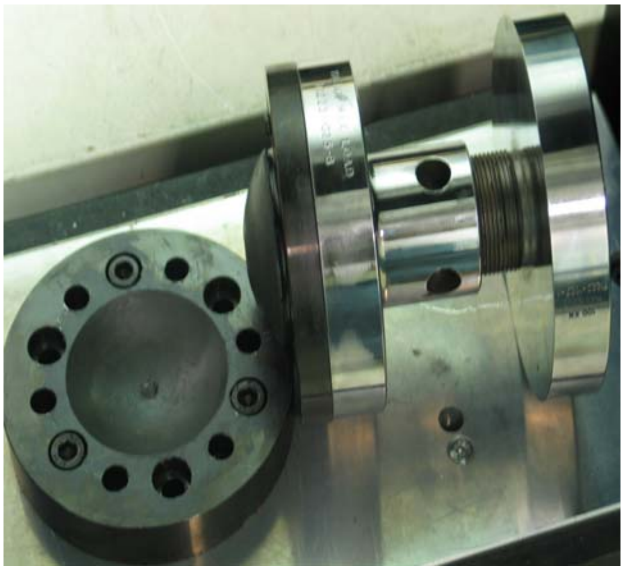

Figure 1. Typical gimbaled platen.

[1]Jadaan, O. M.; Shellman, D. L.; Conway, J. C.; Mecholsky, J. J., Jr.; Tressler, R. E. *Prediction of the Strength of Ceramic Tubular Components: Part I- Analysis*; JTEVA, *19* (3), 1991, pp 181–191.

[2]Shellman, D. L.; Jadaan, O. M.; Conway, J. C.; Mecholsky, J. J., Jr.; Tressler, R. E. *Prediction of Strength of Ceramic Tubular Components: Part II – Experimental Verification*; JTEVA, *19* (3), 1991, pp 192–200.

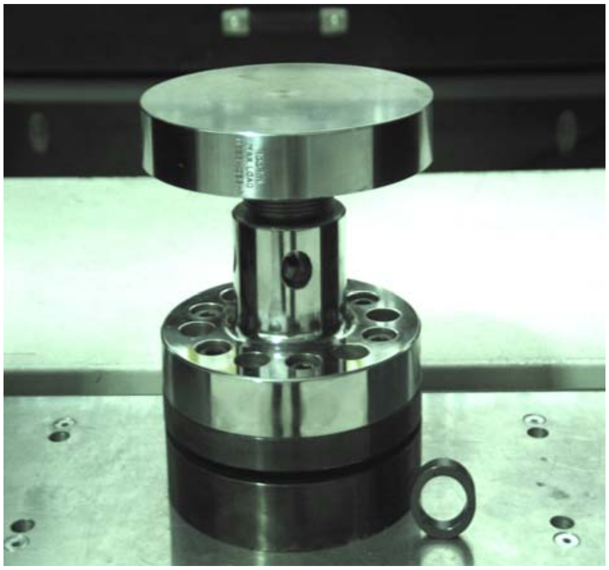

Figure 2. Platen scaled against O-ring specimen.

For room temperature testing the sample may be held in place by the machine operator until there is a sufficient preload on the specimen to maintain alignment.

However, this technique is difficult to perform at elevated temperatures as protective gloves or a means to remotely position the specimen complicate the process. In our particular elevated temperature testing, an induction furnace encapsulates the test specimen which is loaded by long ceramic rams which protrude into this furnace. A model 5500R Instron load frame using BlueHill* test software was configured with a Material Testing Systems (MTS) 657.01 high-temperature furnace and load ram extensions as shown in figure 3. The lower load ram is clamped into a fixture which is bolted to the load frame. The upper load ram is clamped to its mounting fixture which is attached to an MTS 30-kN (6500-lb) load cell via a threaded coupling. Both load rams can be considered rigidly mounted, providing axial alignment but limited alignment in the other dimensions.

2. Testing Ring Samples in the Enclosed Furnace

In the testing described in this report, the ceramic O-ring specimens were cut from ceramic tubes of candidate materials. The nominal specimen's internal diameter (ID) was 24 mm and its external diameter (OD) was 33 mm. A typical sample is shown in figure 4.

*Bluehill is a registered trademark of Instron Corporation (Norwood, MA).

Figure 3. High-temperature furnace with ceramic load rams and compression platens.

Figure 4. The 24-mm ID, 33-mm OD nominal O-ring specimen.

In order to position the specimen for testing within the furnace, which is closed during testing, as seen in figure 5, a fixture was developed by the Ordnance Materials Branch of ARL. The fixture serves two primary purposes. First, it holds the sample upright and centered, so the oven may be closed prior testing. Secondly it provides compensation for any misalignment between the faces of the ram extensions extending from the load head and frame of the test machine into the oven.

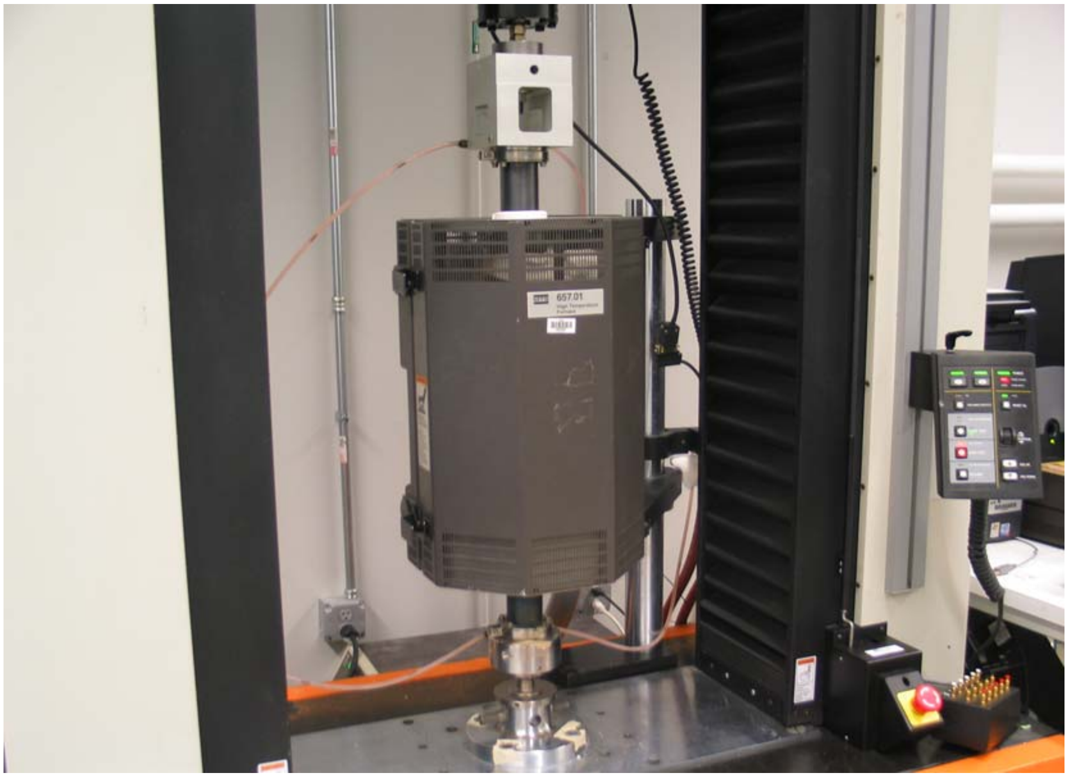

Figure 5. Closed testing furnace.

3. Fixture Description

Figures 6 and 7 are used to describe the components of the alignment fixture and their purposes.

The bottom post has a cylindrical counter bore in its base to align it on the lower ram. The top surface also has a cylindrical counter bore which contains and allows aligning of the ball mount. The ball mount has a centered conical counter sink on the top to provide a pivot surface and align the ball. Thus, the ball is aligned with the axis of loading while providing a pivot for the stand that can move to compensate for any small misalignment between the ram faces.

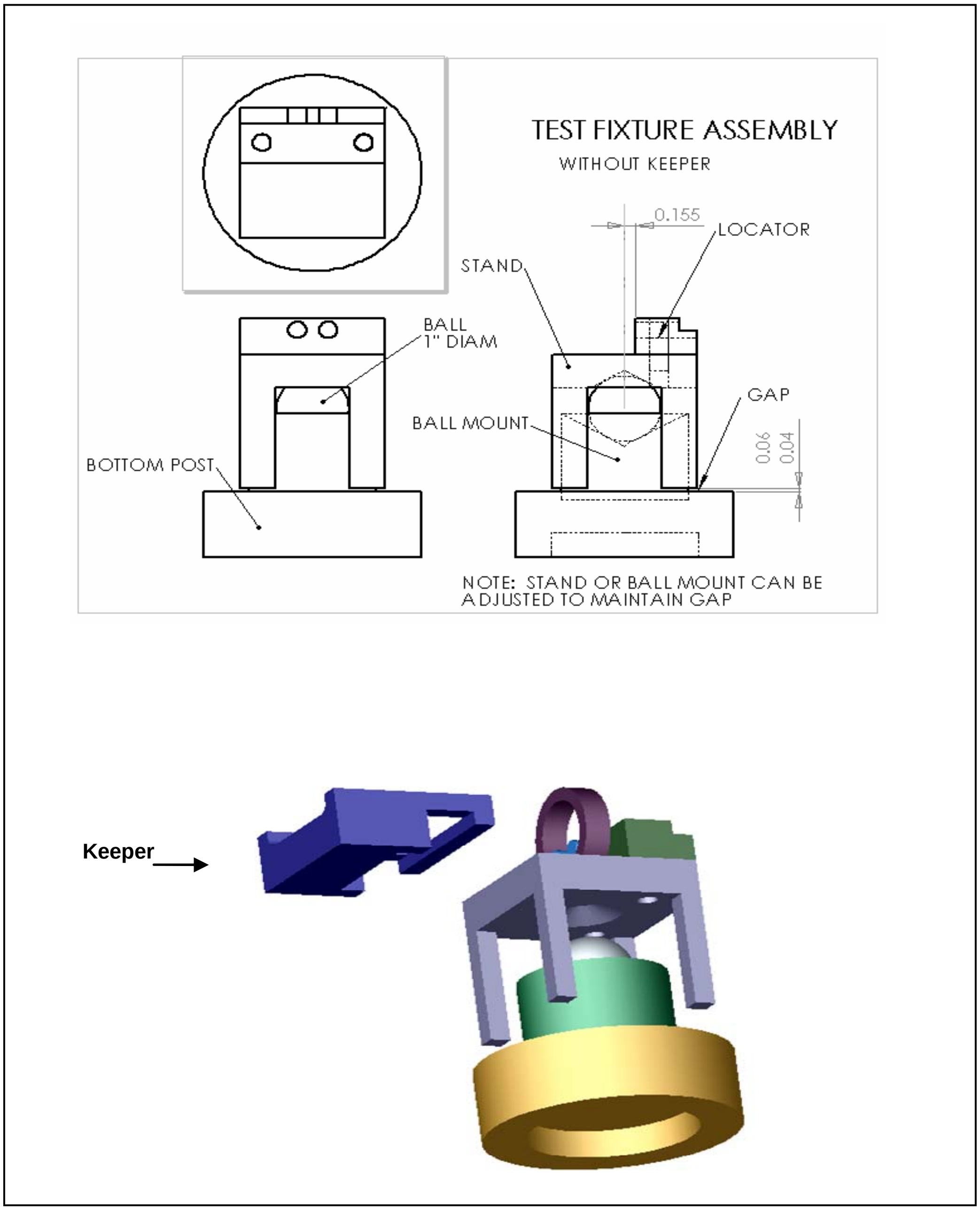

Figure 6. Fixture detail.

The legs of the stand are ~1 mm (0.04 in) short of contacting the base post, when the stand is on the ball. This assures that only a small angle can be present when the top platen contacts the ring specimen. The bottom surface of the test stand has a conical counter bore that centers it on the ball. The ball and contact surfaces are lubricated with graphite powder to allow the fixture to move freely at elevated temperatures.

Figure 7. Complete fixture with O-ring specimen.

A strip of 0.13 mm (0.005 in) of graphite foil is placed in the bottom of the fixture, under the test specimen. This reduces frictional loads and provides some stress distribution at the loading points.

The test specimen is encapsulated by the keeper. The keeper is configured to position the specimen on the centerline of the loading rams. Optional locating pins may be used to locate the specimen prior to attaching the keeper. These pins were determined to be unnecessary for this study and were not used.

A second strip of 0.13-mm graphite foil is placed on the top of the test specimen, between the specimen and the upper platen.

All the components of the fixture, other than the graphite foil, are made of 316 SS for its elevated temperature capabilities.

We have found that graphite foil in excess of 0.13 mm (0.005) thick alters the load/extension curve at higher loads, as seen in figure 8, compared to graphite foil equal to or less than 0.13 mm (0.005 in), as shown in figure 9. This drop in load appears to be associated with the low Poisson's ratio of the foil. A similar response was observed by Woodruff during room temperature testing of SiAlON O-ring specimens.[3]

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[3]Woodruff, A. K. Characterization of Long SiAlON Ceramic Tubes for Gun Barrel Applications. B.S. Thesis, Pennsylvania State University, University Park, PA, April 2005.

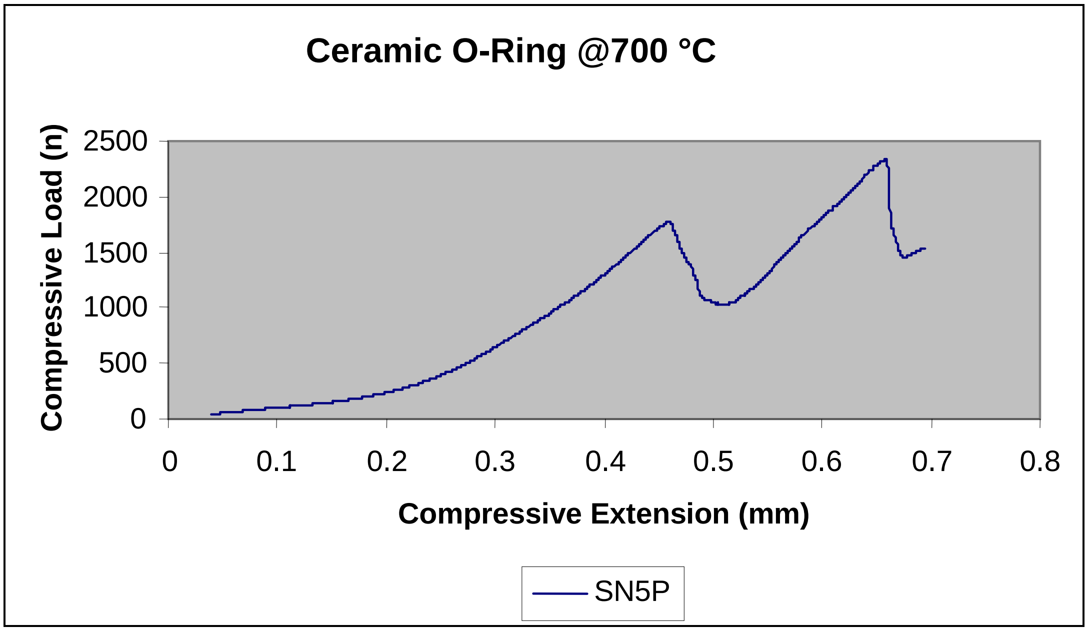

Figure 8. O-ring compressive test results using 0.381-mm (0.015-in) graphite foil.

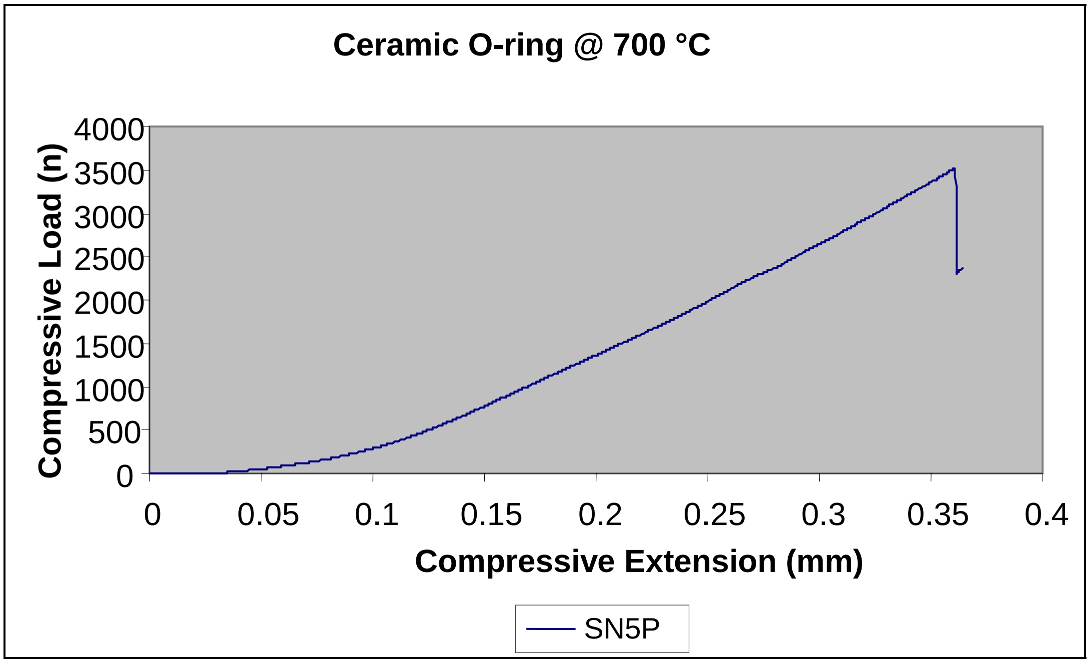

Figure 9. O-ring compressive test results using 0.13-mm (0.005-in) graphite foil.

4. Test Procedure

The load frame used was the Instron Retrofitted 5500R using Blue Hill testing software with an adapted MTS 30-kN (6500-lb) load cell with a cross head rate of 0.1 mm/min. It was configured to use the specimen protect feature that compensates for the thermal expansion of the test fixture during ramp heating and soak time.

The specimen was placed in the fixture according to the procedure described in the previous section.

The furnace used was the MTS 657.01 high-temperature furnace with an operating range of 300–1700 ºC. Temperature ramp rate was 11.66 ºC/min with a 10 min soak time at 700 ºC.

Tests were considered completed when controls detected a 40% load drop from peak compressive load. The load ram was returned to zero after the test was completed.

A typical failed state at the end of a test appears in figure 10. It shows the 0.13-mm graphite foil between the specimen and the top platen. Figure 11 shows a specimen from a successful test.

Figure 10. The 700 ºC failed specimen.

Figure 11. O-ring specimen fractured at 700 ºC. The fracture pattern is indicative of a valid test.

After testing a few specimens it was noted that the test fixture was developing an indentation from the loading of the harder ceramic ring. This was pointed out to the project director who determined it to be nondetrimental to the tests and testing was continued.

5. Conclusions and Recommendations

A test fixture was designed and fabricated to hold and align O-ring test specimens. The fixture also provides test data consistency between the ambient and elevated temperature environments.

Although a slight depression developed in the top surface of the test stand, it functioned adequately. The use of a ceramic insert could be utilized to eliminate this problem.

When thicker 0.381-mm (0.015-in) graphite foil was used to reduce the traction of the loading rams on the ring specimens, its structure affected the loading. It is recommended that graphite foil 0.13 mm (0.005 in) thick or less be used to eliminate this undesirable effect.

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